ARMY HELICOPTER CRASHWORTHINESS

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SUMMARY

Although significant strides have been made in recent years toward improving aviation safety, mishaps involving all classes of helicopters presently are and will continue to be a major, expensive US Army problem in terms of casualties, materiel loss, and reduction in mission effectiveness. Modern-day training and tactical employment requirements for the US Army helicopter dictate that a large percentage of operations occur in the low-speed, low-altitude flight regime, which contributes to the problem by reducing critical margins of safety normally associated with higher airspeed and higher altitude operations with accompanying greater time for response in case of an emergency. This increased probability of accident occurrence, coupled with the lack of an in-flight egress capability, makes design for crashworthiness essential for Army helicopters.

This paper discusses the evolution of crash survival design criteria, its influence on the formulation of a US Army military standard for rotary-wing aircraft crashworthiness, and its application to current and new-generation Army helicopters. Emphasis is given to the need for a total systems' approach in design for crashworthiness and the necessity for considering crashworthiness early in the design phase of a new aviation weapon systems development effort. The actual application of crashworthiness to Army helicopters is presented with statistics that show dramatic reductions in fatalities and injuries with implementation of a crashworthy fuel system. Current and planned US Army R&D to improve crashworthiness technology is discussed, including full-scale crash testing, human tolerance definition, improved energy absorbers, crew restraint systems, and crash impact characteristics of composite helicopter structures. Applicability of the work within Army helicopter crashworthiness to commercial/civil helicopters is shown. The cost effective aspects of designing helicopters to be more crash survivable are also discussed.

INTRODUCTION

Research investigations directed toward improving occupant survival and reducing materiel losses in aircraft crashes have been conducted by the Army for more than 20 years. However, up until approximately 10 years ago the principal emphasis within Army aviation survivability was placed on accident prevention. Although this is indeed the ultimate objective deserving priority effort, past experience clearly shows that accident prevention alone simply is not sufficient. Mishaps of all natures involving Army aircraft have been, are, and will continue to be a major, expensive problem. Research has been accomplished on accidents worldwide involving Army aviation, and accident histories are routinely disseminated throughout the Army. Unfortunately, too many lessons learned from these accident histories are not applied and hazardous design features, human errors, and operational errors are repeated year after year. Too many Army aircrewmen are still being fatally injured in potentially survivable accidents, and the percentage of major injuries and rate of materiel losses are still unacceptably high. There is no easy solution to the problem. Significant gains can be made, however, toward reducing these unacceptable accident losses, but to do so we must aggressively pursue a program that addresses key issues of both accident prevention and crashworthiness design. Since the helicopter's potential for accident is great due to its mission and the environment in which it must accomplish that mission, it is imperative that it be engineered to minimize damage and enhance occupant survival in crashes. In designing helicopters to be more crash survivable, two subissues then become paramount: establishing viable crashworthiness design criteria, and the more difficult task, applying these crashworthiness criteria to Army aircraft design.

To help establish the severity of the problem within US Army aviation, Table 1 provides a summary of accident statistics for Army helicopters for the period of time from 1972 to 1982. With the exception of the OH-6, these aircraft are still in the operational fleet and comprise the bulk of the Army's helicopters. None of these aircraft had crashworthiness in their basic design. During the period reviewed there were over 900 helicopter incidents/accidents with over 400 occupant fatalities. The fatalities would, without question, have been more severe had not the aircraft been retrofitted in the early to mid-70s with crashworthy fuel systems. Considering the personnel aspects in the crashes of these helicopters, the two columns on the right reflect that there were survivors in more than 65 percent of all of the accidents, but, more important, that nearly one-third of all the fatalities occurred in accidents where there were survivors. It can be seen that the costs associated with these accidents in terms of men and materiel replacement are quite high. These costs, however, do not reflect the potentially significantly greater costs

TABLE 1. ARMY HELICOPTER ACCIDENT HISTORY 1972-1982, NONCRASHWORTHY AIRCRAFT

ACFT	NO. OF ACCID	NO. OF PSNL	NO. OF INJURIES MINOR	NO. OF INJURIES MAJOR	NO. OF FATAL-ITIES	COST-$\overline{M}$ (MEN & MATL)	% ACCID WITH SURVIVORS	% FATAL IN ACCID WITH SURVIVORS
UH-1	426	1852	300	210	229	132	82	34
OH-58	235	533	97	76	59	28	86	25
AH-1	156	301	51	37	35	52	88	26
OH-6	72	160	44	19	9	5	93	22
CH-47	32	277	36	9	100	44	78	10
TOTAL ACFT	921	3123	528	351	432	261	85	26

that are associated with loss of mission capability. Further, these statistics are based on current peacetime experience which reflects a total cumulative flight time of approximately 1½ million hours per year for Army aviation with a fatality rate of approximately 2.5 per 100,000 hours of flying time. The severity of the problem increases severalfold during periods of combat, as demonstrated in Vietnam when, during the height of the conflict, total helicopter flight time was in excess of 5 million hours per year with the fatality rate of 10 per 100,000 hours.

Data from these accident and crash injury investigations (Reference 1) have revealed deficiencies in the crashworthiness of the older, existing Army helicopters. Key deficiencies include:

- Structural collapse (roof downward and floor upward) causing loss of occupiable volume
- Inward buckling of frames, longerons, etc., causing penetration wounds to personnel
- Lethal internal structure causing head, chest and extremity injuries from occupant flailing
- Floor breakup permitting seats to tear out and occupants to become flying missiles
- Landing gear penetration into occupied areas and fuel systems causing contact injuries and fires
- Landing gears not designed for sufficiently high sink rates and insufficient deformable airframe structure permitting excessive acceleration (G) forces to be transmitted to the occupants and causing excessive materiel damage
- Intrusion of the occupied area by the main rotor gearbox and other high mass items causing crushing and contact injuries to the occupants
- Insufficient structural stiffness permitting inward crushing and entrapment of occupants in rollover accidents

It has been demonstrated, however, that significant gains can be made toward reducing the severity of these and related problems through the judicious development and application of crashworthiness design features into Army aircraft.

CRASHWORTHINESS DESIGN CRITERIA

In-depth assessment of available crash data was first accomplished in the mid-60s by a joint Government/industry review team. The product of that team was the world's first crash survival design guide for light fixed- and rotary-wing aircraft, published in 1967. Revisions to this guide were made in 1969, 1971, and 1980 (Reference 2). This design guide was subsequently converted into a military standard (MIL-STD-1290) in 1974 (Reference 3) which is presently undergoing revision. MIL-STD-1290 addresses five key areas that must be considered in designing a helicopter to conserve materiel and provide the necessary occupant protection in a crash:

- Crashworthiness of the structure--assuring that the structure has the proper strength and stiffness to maintain a livable volume for the occupants and prevent the seat attachments from breaking free
- Tie-down chain strength--assuring that the high mass items such as the transmission and engine do not break free from their mounts and penetrate occupied areas
- Occupant acceleration environment--providing the necessary crash load absorption by using crushable structures, load limiting landing gears, energy-absorbing seats, etc., to keep the loads on the occupants within human tolerance levels
- Occupant environment hazards--providing the necessary restraint systems, padding, etc., to prevent injury caused by occupant flailing
- Postcrash hazards--after the crash sequence has ended, providing protection against flammable fluid systems and permitting egress under all conditions

A survivable crash is generally defined as one wherein the impact conditions inclusive of pulse rate onset, magnitude, direction and duration of the accelerative forces that are

transmitted to the occupant do not exceed the limits of human tolerance for survival, and in which the surrounding structure remains sufficiently intact during and after impact to permit survival. Thus, helicopters designed to meet MIL-STD-1290 shall be designed to prevent occupant fatalities and minimize the number and severity of injuries during crash impacts of a severity to and including the 95th percentile potentially survivable accident while minimizing aircraft damage to the maximum extent practical. The 95th percentile design pulse generally means that the loads on the occupants would be greater in only 5 percent of the accidents but would still be within the defined human tolerance limits. Table 2 presents the 95th percentile potentially survivable crash design pulse for helicopters expressed in terms of impact velocity change with associated minimum attitude requirements. It should be noted that Table 2 and some of the subsequent discussion reflect criteria that are proposed for the revised MIL-STD-1290 and in some cases deviate from available published design criteria. This approach is meant to enhance the validity and usefulness of this paper. Perhaps the most critical MIL-STD-1290 factor in designing the helicopter for crash survivability is the vertical design impact velocity change requirement. Since the helicopter spends a large percentage of its operational life in

TABLE 2. 95TH PERCENTILE POTENTIALLY SURVIVABLE CRASH IMPACT DESIGN CONDITIONS

IMPACT DIRECTION (AIRCRAFT AXES)	OBJECT IMPACTED	VELOCITY CHANGE (FT/SEC)	MIL-STD-1290 CURRENT			MIL-STD-1290 PROPOSED REVISION		
			PITCH	ROLL	YAW	PITCH	ROLL	YAW
Longitudinal (Cockpit)	Rigid Abutment or Wall	15						
Longitudinal (Cabin)	Rigid Abutment or Wall	40						
Longitudinal (Cockpit & Cabin)	Rigid Surface	50	0	0	0	-5°	$+10^{\circ}$	0
Vertical	Rigid Surface	42	$+15^{\circ}$	$+30^{\circ}$	0	$+15^{\circ}$ to -5°	$\pm 10^{\circ}$	0
Lateral[(a)]	Rigid Surface	25						
Lateral[(b)]	Rigid Surface	30						
Resultant Vector*	Rigid Surface	50						

(a) Light fixed-wing aircraft, attack and cargo helicopters.
(b) Other helicopters.
*Note: The downward, sideward, and forward velocity components of the resultant velocity vector do not exceed 42, 30, and 50 ft/sec, respectively.

the low-speed, low-altitude flight regime, accidents predominantly occur with high vertical descent rates and with the aircraft in a near normal attitude. Thus, the aircraft must withstand vertical impacts of 42 ft/sec, within the aircraft attitude limits of ± 10 degrees roll and +15 degrees to -5 degrees pitch, (1) with no more than a 15-percent reduction in the height of the cockpit and passenger/troop compartments and (2) without causing the occupants to experience injurious accelerative loading. This is a good example of a MIL-STD-1290 proposed revision. The current version states the 42-ft/sec requirement for an aircraft impact attitude within +15 degrees pitch and +30 degrees roll, which not only dictates excessive landing gear capability but does not represent the typical impact as derived from recent analysis of accident data. Based on this recent analysis of roll and pitch frequencies for Army helicopter accidents over the past 10 years, a more detailed representation of the vertical crash impact conditions has been developed and is being proposed as a MIL-STD-1290 revision (see Figure 1). In this case pitch and roll envelopes are specified for vertical velocities of both 42 and 36 ft/sec.

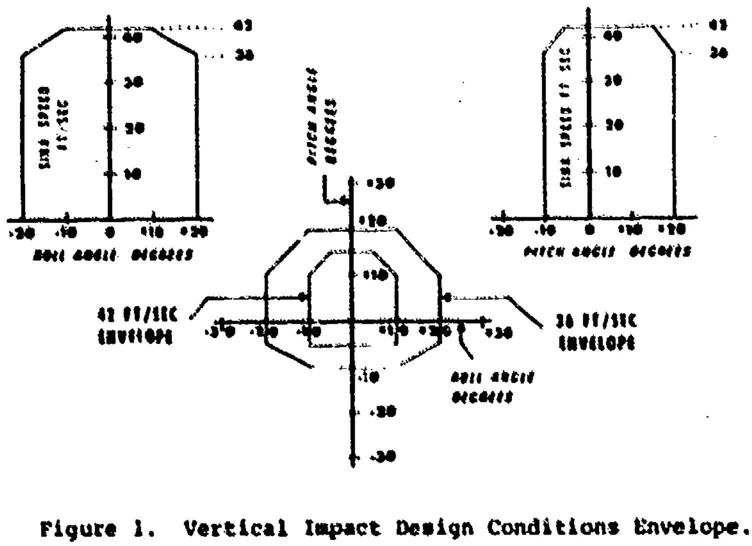

Figure 1. Vertical Impact Design Conditions Envelope.

Other key design impact velocity changes are shown in Table 3. The landing gear shall provide energy absorption capability to reduce the vertical velocity of the fuselage as much as possible under the crash conditions. As a minimum, the landing gear shall be capable of decelerating the aircraft at normal gross weight from an impact velocity of 20 ft/sec onto a level rigid surface within an attitude envelope of ± 10 degrees roll and +15 degrees to -5 degrees pitch without allowing the fuselage to contact the ground and without gear penetration into an occupied area. Plastic deformation of the landing gear and its mounting system is acceptable in meeting this

requirement; however, with the possible exception of the rotor blades, the remainder of the aircraft structure shall be flightworthy after impact. The nose section of the helicopter is to be designed to preclude earth plowing and scooping tendencies when the forward 25 percent of the fuselage is subjected to a longitudinal load uniformly applied with a local upward load of 10 Gs and a rearward load of 4 Gs. The fuselage shall also be designed for rollover protection and shall be capable of sustaining a 4 G load applied uniformly over the fuselage to surface contact area if rollover occurs. Finally, all high mass items which would pose a hazard to personnel during a crash shall be designed to withstand 20 Gs longitudinally, 20 Gs vertically, and 18 Gs laterally when applied separately.

TABLE 3. ADDITIONAL MIL-STD-1290 DESIGN REQUIREMENTS

Landing Gear	20 Ft/Sec, $\pm$ 10° Roll, +15° to -5° Pitch No Fuselage Damage
Plowing & Scooping	10 G Up & 4 G Aft on Fwd 25% Fuselage
Rollover	4 G Side Load 4 G Roof Load
High Mass Tie-down (Applied Separately)	$\pm$ 20 G Longitudinal $\mp$ 20 G/-10 G Vertical $\pm$ 18 G Lateral

For maximum effectiveness, design for crashworthiness dictates that a total systems approach be used and that the designer consider survivability issues in the same light as other key design considerations such as weight, load factor, and fatigue life during the initial design phase of the helicopter. Figure 2 depicts the system's approach required relative to management of the crash energy for occupant survival for the 95th percentile vertical crash pulse design condition. The crash G loads must be brought to within human tolerance limits in a controlled manner to prevent injury to the occupants; this can be accomplished by using the landing gear, floor structure, and seat to progressively absorb most of the crash energy during the crash sequence. Thus, the occupant is slowed down in a controlled manner by stroking/failing the landing gear, crushing the floor structure, and stroking the seat at a predetermined load before being subjected to the crash pulse which by then has been reduced to within human tolerance limits. In addition, the large mass items such as the overhead gearbox are slowed down by stroking/failing of the landing gear or fuselage structure, and in some cases, by stroking of the gearbox within its mounts. In this example, assuming that the landing gear has been designed to meet the minimum requirements of MIL-STD-1290, i.e., 20 ft/sec, the fuselage would be decelerated to approximately 37 ft/sec at the time of contact with the surface.

The Army's most recent helicopters, the UH-60 BLACK HAWK and AH-64 APACHE, are both designed generally in accordance with the requirements of MIL-STD-1290, and the significant payoff for designing these aircraft for crashworthiness will be addressed later.

The preceding discussion should not be interpreted, however, to imply that nothing can be done for existing aircraft systems. Quite the contrary. Considerable improvement in crashworthiness can be achieved on existing helicopters by applying such features as improved crew restraint systems, energy-absorbing seats, crash tolerant fuel systems, and breakaway control sticks.

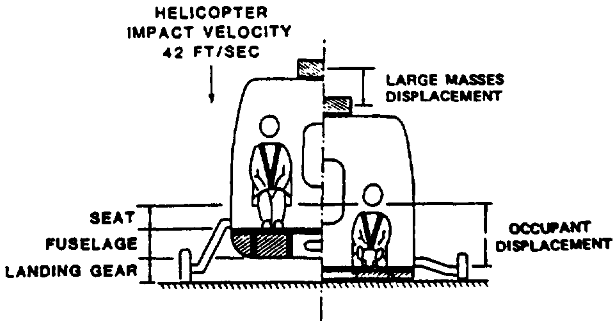

Figure 2. Energy Management System.

Also, the above discussion of crashworthy requirements principally addresses the airframe, the main objective of which is to provide a protective shell for the occupants and to allow deformation of the structure in a controlled, predictable manner to minimize forces on the occupants. Other key requirements in MIL-STD-1290 in designing a helicopter system for crashworthiness include:

- Occupant restraint design--Seats and litters shall be designed to retain occupant position during crash and shall contain integral means of crash force attenuation. Crew seats shall be designed to permit the seat to stroke 12 inches vertically. The immediate surroundings shall be designed to minimize occupant injury when body parts flail in a crash. These designs shall be applicable with the 5th through the 95th percentile male aircrewman (i.e., 133-lb thru 212-lb crewman).

- Cargo and equipment restraint system design--The design shall provide sufficient restraint of all cargo and high mass equipment in all directions to prevent injury to occupants in the 95th percentile survivable accident.

- Postcrash fire prevention design--All flammable fluid systems shall be designed to minimize spillage of fluids during and after survivable crash impacts, and when spillage cannot be avoided, the system shall be designed to prevent ignition of the fluids to the maximum extent practical.

- Postcrash emergency escape provisions design--The design shall provide for sufficient size and quantity of exits to allow occupant escape within 30 seconds after the crash sequence is over (including ditching) even when half of the exits are blocked off.

CRASHWORTHY R&D PROGRAM HIGHLIGHTS

Considerable effort has been accomplished in the past and is presently ongoing in the area of helicopter crashworthiness research and development. Efforts include such diverse areas as human tolerance definition, crashworthy troop and crew seats, improved restraint systems, crashworthy fuel systems, math modeling of crashworthy structures, crashworthy composite structures, and full-scale crash testing of both crashworthy and noncrashworthy aircraft. Results of these efforts are applicable to both the retrofit of existing aircraft systems, to improve their survivability/mission capability, and to the definition of design criteria and publication of specifications and standards for crashworthy design of new systems. Highlights of key crashworthy R&D programs within the US Army are presented in the following paragraphs.

Crash Impact Characteristics of Helicopter Composite Structures

In recent years, composite materials such as graphite, fiberglass, boron and Kevlar have been used more extensively in the design of structural and nonstructural aircraft components due to their potential for cost and weight savings. Entire composite airframes have already been produced for general aviation fixed-wing aircraft. It is therefore reasonable to assume that in the near future the helicopter industry will be producing large numbers of aircraft with major structural components, such as the fuselage, wings, empennage, blades, and landing gear, constructed of composite materials. In view of the crashworthiness requirements specified in MIL-STD-1290, it was considered particularly appropriate during the early stage of application of composite materials to helicopter structures to investigate their crash impact behavior. When applying composites to a crashworthy airframe structure, entirely different design concepts may be required than are used with conventional metal structures. Composite materials exhibit low strain-to-failure compared to such metals as 2024 aluminum, a ductile metal that can tolerate rather large strains, deform plastically, and absorb a considerable amount of energy without fracture. Because of this difference between composites and metals, crash energy absorption with composites will not come through material stress-strain behavior as it did with metals, but rather through innovative design.

To determine the crashworthiness characteristics of helicopter composite structures, a program was conducted for the design, fabrication, design support testing, analysis and crash testing of two full-scale composite helicopter cabin sections. Crash tests were conducted for 0- and 20-degree roll impact attitudes at a vertical impact velocity of 30 ft/sec, which is representative of the Army's vertical impact velocity requirement (MIL-STD-1290) for noninjurious loadings if the landing gear is assumed to absorb approximately one-half the impact energy.

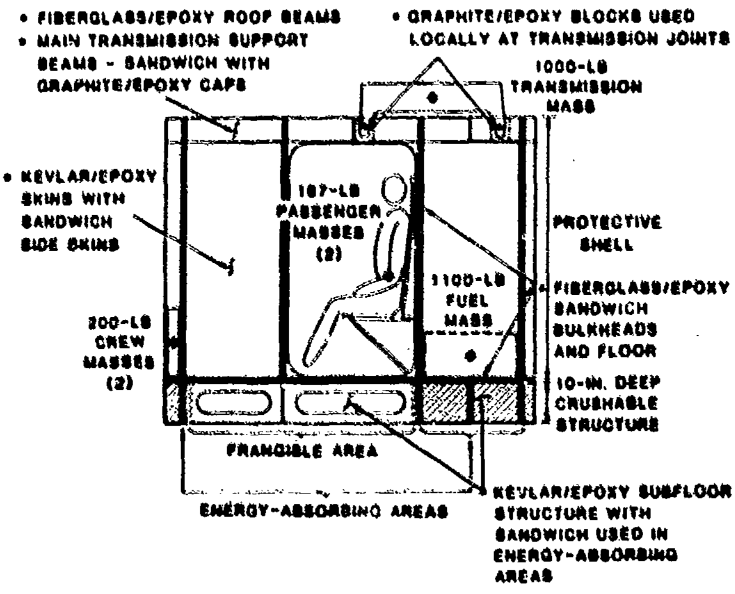

Figure 3. Composite Cabin Test Section Design Features.

The cabin section (Figure 3) had three major bulkheads: the forward crew bulkhead, the aft cabin bulkhead, and the aft fuel cell bulkhead. The masses in the cabin were a 1000-pound overhead transmission mass, 1100 pounds of fuel, two 167-pound passenger masses, and two 200-pound forward crew masses. Located directly beneath the forward crew bulkhead and the aft two bulkheads was a crushable cabin subfloor structure designed to absorb energy and control loads to the primary protective shell. Between the crush zones was frangible structure that would crush out of the way without damaging the floor structure.

Kevlar, fiberglass, and graphite/epoxy materials were used in constructing the cabin section. Fiberglass sandwich construction was used in the bulkheads and floor panel, and in portions of the upper roof structure. Kevlar was used in the roof, belly and side skins, and in the energy-absorbing subfloor structure. Graphite reinforcement was used around the door frame and in the main roof beams. Figure 4 depicts the cabin components. For the first test, two stroking seats equipped with wire-roller attenuators were installed in the cabin. The right seat was floor-mounted and the left seat was bulkhead-mounted. Fiftieth percentile Part 572, Hybrid II anthropomorphic testing dummies were placed in the seats. The impact was on a simulated rigid surface comprised of steel plates over a sand base. Instrumentation included accelerometers on major masses and important structural locations, and high-speed motion picture cameras were used to record the structure response and failure modes. The level attitude 30 ft/sec vertical velocity (or about 14 feet free fall height) composite cabin section drop test was survivable based on the excellent post-test condition of the cabin protective shell structure and the performance of the energy-absorbing structure components (see Figure 5). There was approximately 4 inches of subfloor crush. The bulkhead-mounted left seat stroked 9 inches and the floor-mounted right

seat stroked 6 inches. Figure 6 depicts the vertical acceleration time history of the left troop seat dummy pelvis and floor for the flat impact test. This vividly shows how the stroking seat prevented injurious accelerative loadings from being transmitted to the dummy. Both seats had an 11-inch stroke capability and therefore did not bottom out. The 1000-pound overhead transmission mass stroked about 1.25 inches in the specially designed roof beam attachment joints.

The second cabin section was equipped with lumped masses for the passengers in lieu of stroking seats and dummies. This was done in order to reduce the complexity of the test specimen in the severe 20-degree roll impact condition. During the test, the cabin impacted on the left side at 20-degrees roll with very little rotation before the vertical velocity was attenuated. The cabin then rolled over on the right side with little vertical kinetic energy at that time, which is indicated by the right side crushable structure not being damaged (see Figure 7). The test verified that the crushable energy-absorbing structure can tolerate an oblique impact with combined loading and still perform well and protect the structure surrounding the occupied volume.

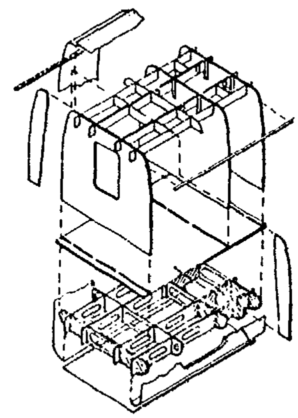

Figure 4. Composite Cabin Components.

An important part of this program was to evaluate analysis methods that could be useful tools in future design of crashworthy structures. The KRASH and DYCAST computer programs were used for dynamic analysis of the crash impact conditions, while NASTRAN was used to develop internal loads in the structure. Load factors were determined from the

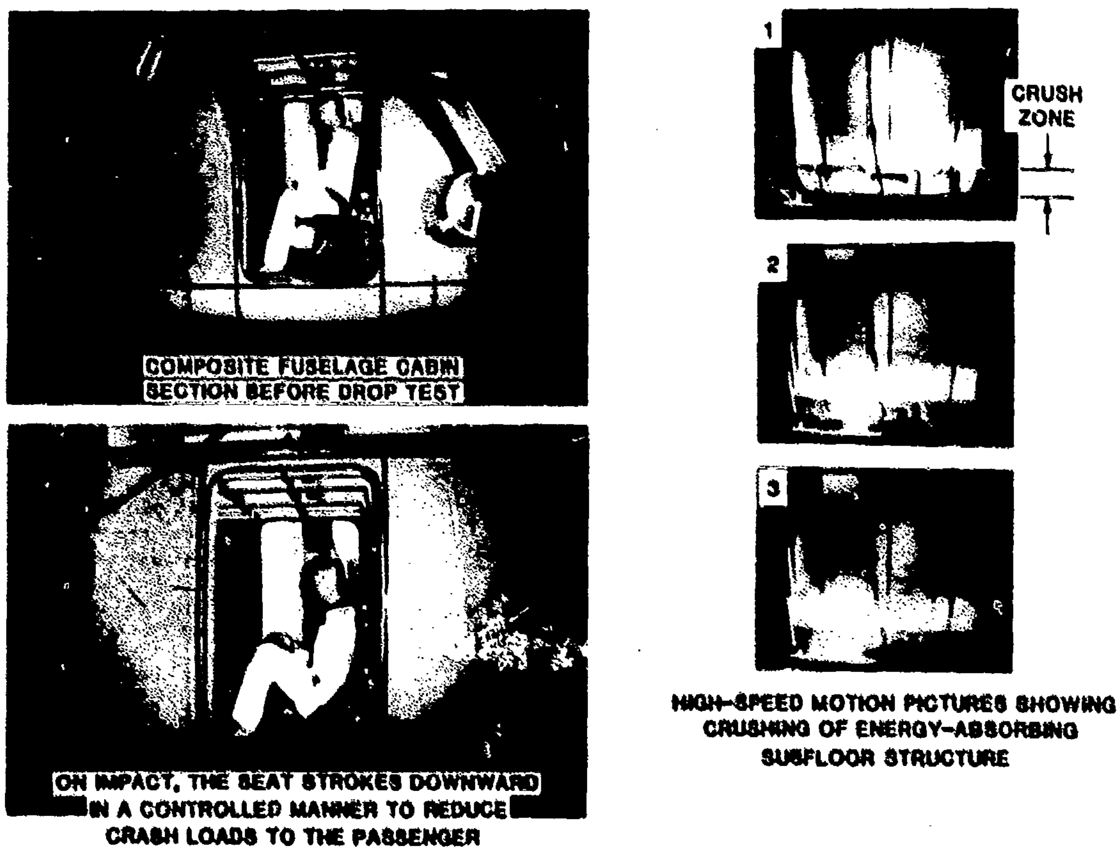

Figure 5. Flat Drop Test.

KRASH dynamic analysis for major mass items such as the crew, troops, fuel, and transmission and were applied to the NASTRAN finite element model of the cabin section. In addition, the crush zone loads were applied to the floor. The NASTRAN model was then used to develop internal loads to be used for the strength analysis. Critical areas in the primary structure components were sized using the internal loads from the NASTRAN mode. Some of the important critical areas were the main roof beams that support the transmission mass, the aft cabin bulkhead, the roof and side skins, and the floor panel loaded by the fuel mass. The crushable subfloor structure was sized based on design support testing data to get the proper energy absorption and control of loads to the primary protective shell structure. As a result of this research, it was concluded that:

- MIL-STD-1290 crashworthiness requirements can be met with a composite fuselage structure if designed with energy absorption and load attenuation in controlled areas.

- The use of design support testing to size and optimize the load deflection characteristics of composite material energy-absorbing components is an accurate, economical approach.
- The KRASH (supplemented with NASTRAN) and the DYCAST nonlinear, large-deflection structure crash simulation computer programs can be useful and reasonably accurate analytical tools for designing the crashworthy composite fuselage cabin sections.

Additional details on this program are provided in Reference 4.

Human Tolerance

A major objective of Army crashworthiness is to attenuate crash loads reaching the occupants to levels within the limits of human tolerance. To properly design to meet this objective, limits of human tolerance to acceleration about all aircraft axes must be accurately defined. This is an extremely difficult set of data to obtain since human tolerance to impact forces varies appreciably with an individual's age, sex, weight distribution, and general state of health. Army helicopters can normally be expected to be occupied by personnel who are younger and in better physical condition than that of the general population for which most of the tolerance data have been developed to date. Thus, a degree of conservatism may be built in for the military in using criteria developed from a "general public" cross section. However, these tolerance criteria have for the most part been based on experiments involving subjects seated with a "correct" upright posture, while Army aviators spend large portions of their time while in the aircraft in less-than-ideal postures for absorbing crash impact (e.g., viewing through target designating/sighting scopes). During nap-of-the-earth flight operations, a crewman can expect little warning of an impending crash impact and will virtually have no time for assuming a proper pre-impact posture.

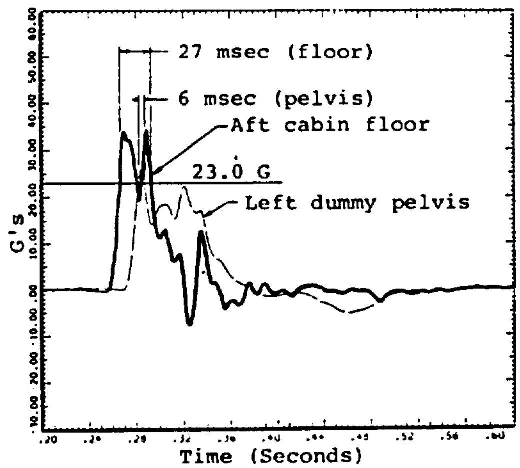

Figure 6. Vertical Acceleration Time-History of Left Troop Seat Dummy Pelvis and Floor For Flat Impact.

With proper restraint, aircraft occupants can withstand the full 95th percentile survivable crash acceleration conditions in the lateral (G_y) and longitudinal (G_x) directions with no energy absorption. Such is not the case with accelerations directed along the vertical axis, particularly headward ($+G_z$) acceleration. The lumbar vertebrae of the occupant, which must support most of the upper torso loaded as a column, are susceptible to compression fracture with attendant injuries such as paralysis. To prevent the occupant from experiencing injurious accelerative loadings, energy attenuation, in the form of energy-absorbing landing gear, crushable belly structure, and stroking seats, is required to control vertical loads.

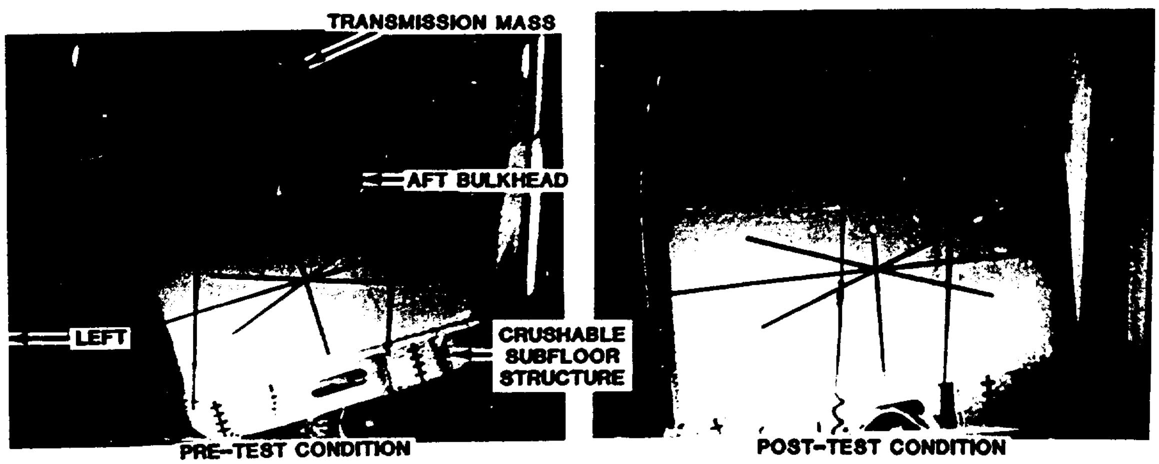

Figure 7. Twenty-Degree Roll Drop Test.

Current Army criteria are based on the Eiband[5] human tolerance data for the upper limit of tolerable (with no injury) acceleration in the $+G_z$ direction (see Figure 8). These data establish the upper limit for vertical acceleration excursions transmitted to the occupant to magnitudes of less than 23 G for time durations exceeding 6 milliseconds. The Army crashworthy crewseat specification, MIL-S-58095[6], has placed this limitation on the seat pan accelerations while the seat is subjected to dynamic testing defined in Figure 9. In seat tests conducted since the specification was established in 1971, a characteristic curve (Figure 10) shows that the seat pan deceleration rises sharply during the onset of the input pulse, then drops rapidly as the seat becomes fully coupled to the

occupant. The deceleration may actually pass through zero (constant velocity) as this event occurs. The deceleration then rises sharply and forms a secondary spike before damping out around the load factor used in the design of the seat energy-absorbing system. The primary seat pan deceleration spike is of little concern since it represents the response of the unloaded seat to the impact event. The secondary spike, however, occurs after the seat cushion and buttocks have compressed and, in most tests, its duration above 23 G exceeds the Eiband injury criteria. The body is a complex dynamic system when one considers the pelvis, chest and head as masses being interconnected by flesh and spinal column "springs." Whether the characteristic secondary spike indeed applies injurious loads to any part of the spine is still largely unknown. Accordingly, research is being conducted to better define human tolerance to injury as related to the typical Army aviator. This includes advanced energy absorber research and research involving cadaver testing.

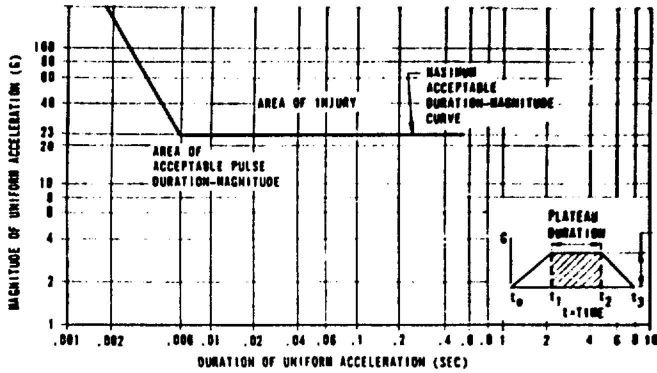

Figure 8. Maximum Acceptable Vertical Pulse Acceleration and Duration Values.

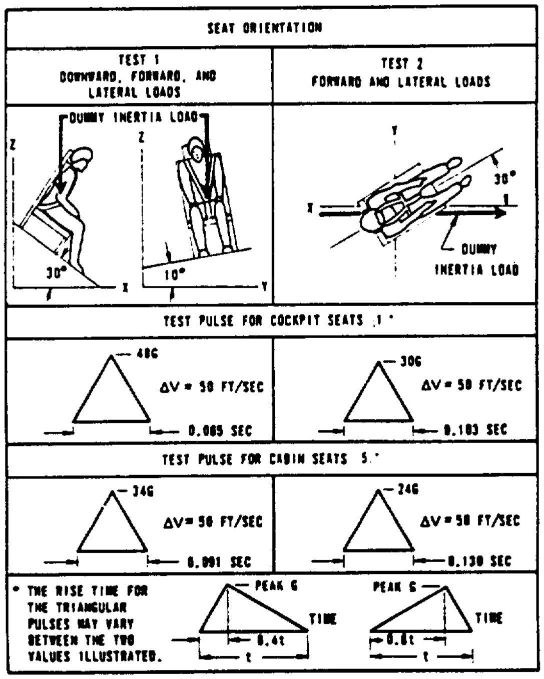

Figure 9. Dynamic Test Conditions for Aircraft Seats.

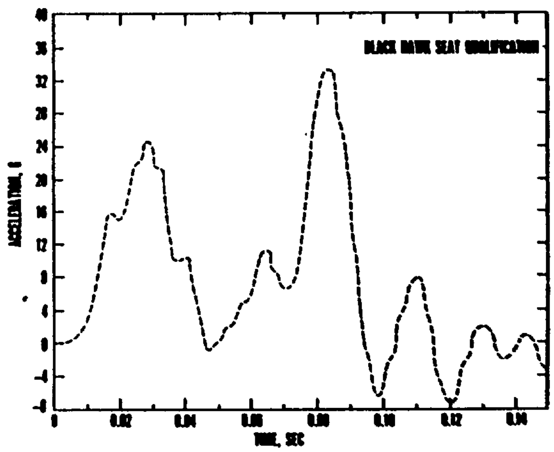

Figure 10. MIL-S-58095 Test No. 1 Seat Pan Vertical Accelerations.

Since mid-1979, the Army has been jointly involved with its sister services and the FAA in sponsoring tests to establish the threshold of human tolerance to spinal compressive loads. Testing has been performed at the Wayne State University Bioengineering Center on their WHAM III (Wayne Horizontal Accelerator Mechanism) sled. This testing has involved the use of human cadavers in both rigid (nonstroking) seats and the production BLACK HAWK helicopter crashworthy crewseat. Tests of three embalmed cadavers in the rigid seat gave mixed results, with spinal fractures occurring at 7.5 G, 28.5 G, and 13.0 G. These results were achieved by testing each cadaver to progressively higher peak impact G loading with the impact vector being parallel to his spine. X-rays were taken between runs until a spinal fracture was indicated. Table 4 summarizes the results for these three tests.

An unembalmed cadaver test series is presently ongoing using the BLACK HAWK crewseat having a 12- to 17-inch stroking capability depending on seat height adjustment. This testing has been performed with two seat orientations: one to simulate a "flat" or 0-degree pitch angle BLACK HAWK ground impact (referred to as the "vertical" mode) and another to simulate a 30-degree nose-down BLACK HAWK ground impact (referred to as the "combined axis" mode). The sled impact pulse has approximated a 41 G triangular pulse of 64 milliseconds duration for a velocity change of 42 ft/sec. This is representative of the Army's 95th percentile potentially survivable impact. Testing has been conducted

TABLE 4. SUMMARY OF TEST CONDITIONS FOR RIGID SEAT TESTS WITH EMBALMED CADAVERS

TEST NO.	CADAVER NO.	AGE	HEIGHT	WEIGHT (LB)	SEX	PEAK ACCEL. (G)	FRACTURE CONDITION
SERIES #1 (3 RUNS)	4612	52	5' 10"	161	M	4,6,8	T9 @ 7.5 G
SERIES #2 (11 RUNS)	4654	49	5' 7"	202	M	4 TO 30	T10 & T11 @ 28.5 G, COMPRESSION FAILURE
SERIES #3 (8 RUNS)	4660	51	5' 7"	216	M	4 TO 30	T8 @ 13 G, ANTERIOR WEDGE FRACTURE

with seat energy attenuators (EA's) set for 14.5, 11.5, and 8.5 G stroking loads based on a 50th percentile seat occupant. Table 5 lists pertinent data relating to each test in this series with cadaver injury condition determined by post-test autopsy.

TABLE 5. SUMMARY OF TEST CONDITIONS FOR UH-60A CREWSEAT TESTS WITH UNEMBALMED CADAVERS

TEST NO.	TEST CONDITION	IMPACT MODE	AGE/SEX	HEIGHT	WEIGHT (LB)	INPUT VELOCITY CHANGE (FT/SEC)	INPUT PEAK ACCEL. (G)	VERTEBRAL INJURY CONDITION
AF020	14.5 G E/A	VERT	44/F	5' 3"	166	41.5	43.4	NONE
AF021	14.5 G E/A	COMB	44/F	5' 3"	166	42.6	44.4	T12 END PLATE, C1-C2 ARTICULATION
AF025	14.5 G E/A	VERT	55/M	5' 7"	160	-	-	L3, ANTERIOR WEDGE FRACTURE
AF028	14.5 G E/A	VERT	61/F	5' 4"	140	45.5	43.2	NONE
AF029	14.5 G E/A	COMB	61/F	5' 4"	140	44.0	42.4	T12, ANTERIOR WEDGE FRACTURE
AF031	14.5 G E/A	VERT	63/F	5' 5½"	148	43.0	39.8	T8, COMPRESSION FRACTURE
AF033	11.5 G E/A	COMB	52/M	5' 9"	218	41.8	45.0	L1, ANTERIOR WEDGE FRACTURE
AF035	11.5 G E/A	COMB	63/M	5' 8"	141	44.7	40.5	L3, ANTERIOR WEDGE FRACTURE
AF037	11.5 G E/A	COMB	58/F	5' 3"	160	46.6	40.9	L3, ANTERIOR WEDGE FRACTURE
AF039	8.5 G E/A	COMB	52/M	5' 10"	200	41.0	37.9	NONE
AF040	8.5 G E/A	COMB	63/M	5' 6½"	142	38.0	35.7	L2, END PLATE FRACTURE
AF041	8.5 G E/A	COMB	54/M	5' 10"	165	36.2	35.0	NONE
AF042	8.5 G E/A	COMB	47/M	5' 10"	155	42.2	42.9	C2 FRACTURE, T9, L4 COMPRESSION FRACTURE

The average age of cadavers tested to date is 54.6 years. Questions have been raised (and justly so) regarding any differences in spinal compressive strength that may exist between these cadavers and the younger occupants typically involved in Army aviation mishaps. Although control is exercised over cadaver selection by rejecting any having died from long-term or degenerative illnesses, other factors relating to aging such as osteoporosis may be present. Medical doctors associated with the program have estimated spinal tolerance of these cadavers to be approximately one-half that of Army aviators. Crush tests were performed of excised spines from six of the test cadavers to determine their stiffness and ultimate compressive strength. Bone mineral assay tests were also performed in an attempt to achieve a mineral content-to-strength correlation. Neither of these procedures yielded usable results, it is felt mainly due to the low sample size.

Throughout the cadaveric testing, the dynamic behavior of the test subjects has raised a concern, particularly in the combined axis impacts. High speed movies show that the head and torso of most subjects undergo severe hyperflexion in spite of the deliberate and consistent pretensioning of the 5-point restraint harness built into the test procedure. The lap belt and each shoulder harness are tightened to 50 pounds and 30 pounds, respectively. In several cases, the head dips between the knees at the peak of its excursion. In the test film, the subject's shoulders and upper torso appear to roll under the shoulder harness to a degree not seen previously in comparable tests with anthropomorphic dummies. The observed motion, if present in live occupants, increases the likelihood of two types of injury: (1) the anterior "wedge-type" vertebral fracture caused by increased pressure on the anterior side of the vertebrae and (2) secondary impact type injuries sustained when the head/neck contact fixed cockpit furnishings located in the crewman's strike envelope.

Two additional tests are presently scheduled in the cadaveric series. Though the simulation of helicopter crash impacts using cadavers is a viable method for injury

studies, much work remains in establishing human tolerance levels from cadaveric data.

Crashworthy Seat Design Criteria

In addition to crashworthy armored crewseats in the Army's UH-60 and AH-64 helicopters, lightweight crashworthy troop seats have been developed and are installed in the cargo/troop compartment of the UH-60. These seats are constructed of tubing covered with fabric and are ceiling-suspended and floor-stabilized to provide energy attenuation in the vertical, forward and lateral directions. A compact wire-bending attenuator is used for vertical impact loads and a four-point restraint system having a single release buckle is attached to the seat. These troop seats, weighing approximately 18 pounds each, have quick disconnect fittings allowing for quick conversion of the aircraft to carry cargo.

Because of the need to develop improved criteria for the load-deflection characteristics of crashworthy seat energy absorbers, an extensive test program was initiated by the Army with joint participation by the FAA's Civil Aeromedical Institute (CAMI) and the Naval Air Development Center (NADC). A matrix of 59 dynamic impact tests were conducted using a production US Army BLACK HAWK helicopter crewseat as a baseline. Variables that were investigated included the shape, magnitude, and rate of onset of the input deceleration pulse; the velocity change; the type and size of the anthropomorphic dummy; the energy absorber limit load; the movable seat weight; the seat cushion characteristics and orientation to the input pulse; and the structural spring rate of the seat. Simula, Inc., provided test support, data reduction and analysis, and correlation of results with computer program SOM-LA (Seat/Occupant Model - Light Aircraft). Testing was conducted at CAMI (47 tests), NADC (9 tests), and Simula, Inc. (3 tests) to assess the effects on dynamic response of each test facility's unique input pulse shape. Figure 11 shows baseline 42 G input pulses produced by each test facility compared to the idealized prescribed triangular pulse.

Though space limitations do not permit the relating of results of each parametric variable, important relationships and sensitivities were established. For example, tests with "ramped" energy absorbers, whose loads increased throughout the seat stroke, revealed that they performed less efficiently than conventional square-wave type devices. The ramped devices caused the dummy to utilize more than 1.5 inches of additional stroke, while the measured accelerations and calculated dynamic response indices (DRI's) were actually higher. The dynamic response index is a dimensionless parameter resulting from a single lumped-mass, damped-spring model of the body mass acting on the human spine. It represents the human response to short-duration accelerations applied in an upward vertical direction parallel to the spine. The US Air Force uses DRI as one of its ejection seat acceptance parameters.

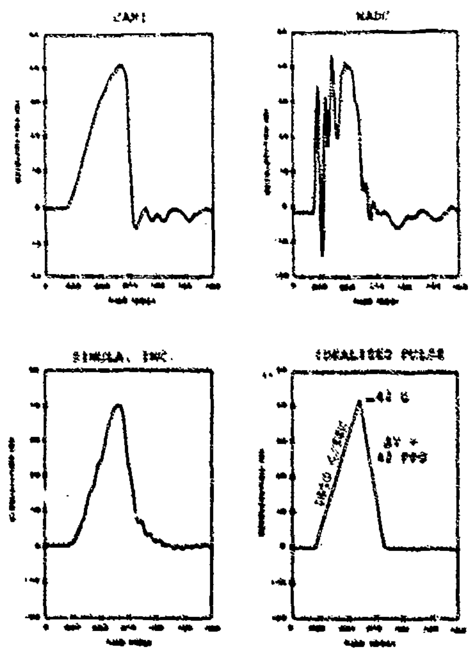

Figure 11. Typical Baseline Deceleration Pulses Compared to Idealized Pulse.

Another significant test series, sponsored by the US Army Aeromedical Research Laboratory (USAARL), contributed to the overall interpretation of data obtained from all of these test programs. A 50th percentile (Part 572) anthropomorphic dummy and a 95th percentile (VIP-95) dummy were modified to install a six-axis load cell at the base of their lumbar spines. The VIP-95 also received a six-axis cervical load cell. The dummies were then subjected to several dynamic impact tests at CAMI, some of which duplicated earlier test conditions. Results indicated that direct measurement of spinal loads in this fashion may provide a better standard for judging crashworthy seat injury criteria. More work needs to be done in order to achieve a noninterfering load cell installation, since duplicative test conditions revealed some changes in the modified dummy dynamic behavior. Reference 7 reports results under this effort and includes recommendations for future crashworthy seat specification updating.

Restraint System

The occupant restraint system is literally the "first line of defense" in preventing aircraft crash injuries. This system includes not only the belted occupant restraint but also a properly engineered mounting of the seat in the aircraft. This combination keeps the occupant from becoming a flying missile during the crash sequence. MIL-S-58095 has been the Army's crashworthy pilot/copilot seat and restraint system criteria document since 1971. A five-strap belted restraint is required consisting of the lap belts, two shoulder straps with an inertia reel, a negative G strap, and a single point of attachment buckle. The negative G strap is permanently affixed to the buckle and requires use at all times to ensure against occupant submarining under the lap belt.

The compactness of today's cockpit and the close proximity of mission equipment pose serious crash impact hazards to the aircrew. Although not desirable from a crashworthiness standpoint, operational considerations dictate that mission equipment and structure be located within the occupant's crash impact motion envelope. Given this situation, it is critical to the occupant's crash impact survival chances that he be provided with a

restraint system that minimizes his crash impact motion envelope, particularly concerning his head.

During 1979, the Army tested seven types of pilot/copilot restraint systems under dynamic impact conditions representative of various degrees of survivable crash conditions. Thirty-three dynamic impact sled tests were performed using a 95th percentile anthropomorphic dummy as the occupant. Restraints tested represented a cross section of those currently available with features such as a reflected strap shoulder harness and power haulback inertia reels. Another concept tested was a joint Army/Navy modification to the MIL-S-58095 restraint called the Inflatable Body and Head Restraint System (IBAHRS), which capitalizes on automotive air-bag technology to better restrain the occupant in severe impacts. This system (Figure 12) uses an airframe-mounted crash sensor to identify a crash condition and then trigger the inflation of air bags sewn into each shoulder harness. Inflation is accomplished by a solid propellant gas generator within approximately 25 milliseconds from being triggered, and the air bags remain inflated for approximately 1½ seconds. The inflated bags act to tighten the restraint about the crewman, better distribute the decelerative loads over his upper torso, and decrease head and neck rotation. Figures 13 and 14 depict the reduction in strike envelope determined experimentally during the 1979 Army tests. Figure 13 is for the conventional MIL-S-58095 restraint and Figure 14 shows the improvements when using the IBAHRS. Both tests were conducted at the 95th percentile potentially survivable crash pulse. Results on this complete test series are reported in Reference 8.

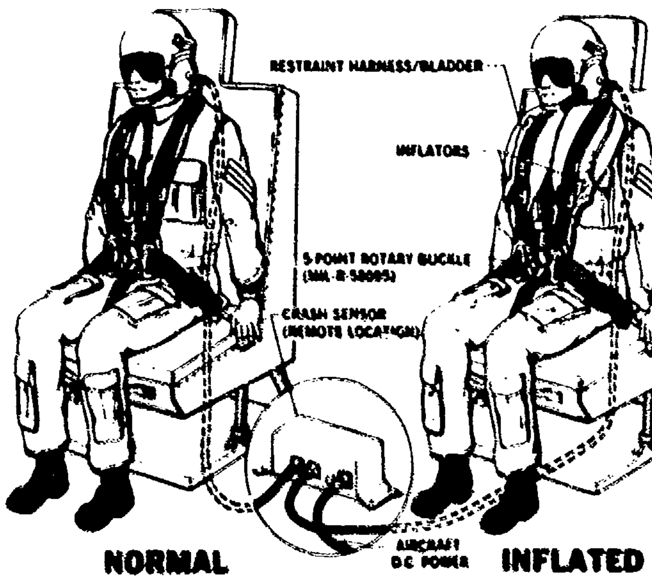

Figure 12. Inflatable Body and Head Restraint System (IBAHRS).

The activating crash sensor for the IBAHRS must be tailored for the particular aircraft application, and it must not allow triggering during routine flight maneuvers or from vibratory or gust loads or hard (autorotative) landings. The crash sensor threshold accelerations for the Army's AH-64 attack aircraft are shown in Figure 15 (from Reference 9) for G loadings directed along the vertical and longitudinal axes. It is obvious, however, that each aircraft type and mission scenario would have to be examined carefully before selecting the crash sensor characteristics for an IBAHRS. For example, an aircraft with 6 G sustained turn capability could not use the AH-64 crash sensor.

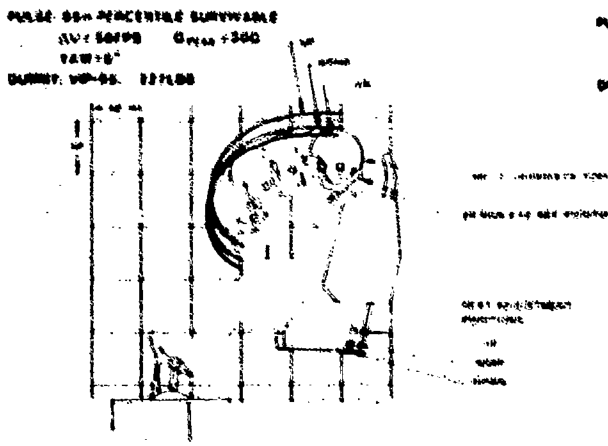

Figure 13. AH-64 Copilot/Gunner Strike Envelope With MIL-S-58095 Restraint.

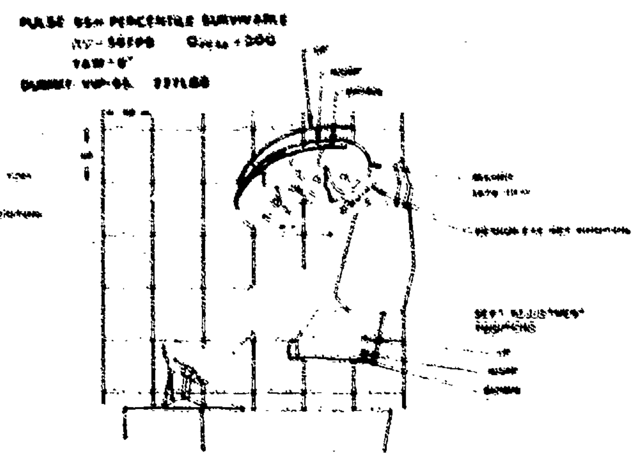

Figure 14. AH-64 Copilot/Gunner Strike Envelope With IBAHRS.

The IBAHRS is currently proceeding through detailed engineering development tests. It will become the standard restraint system for the AH-64 and AH-1S attack helicopters after production approval is given.

Crashworthy Cyclic Control Stick

The floor-mounted, rigid cyclic stick has been a cockpit strike hazard for many years. It has been a major contributor to scores of head injuries and fatalities. A survey of

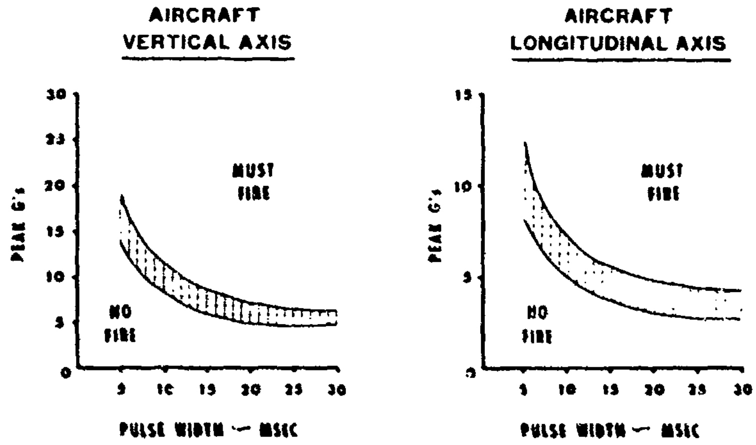

Figure 15. AH-64 IBAHRS Crash Sensor Thresholds.

Army accidents involving 4550 occupants indicates that over 36 percent of the 456 fatalities were due to head and face injuries (Reference 2, Vol. II).

In 1982 the US Army initiated a research effort to develop a cyclic control stick capable of meeting the military specification requirements for normal and emergency control loads as well as having breakaway/telescoping characteristics when struck from above by the crewman in a hard landing/crash. The design is to be generic for retrofit in both the AH-1 and UH-60 aircraft. The vertical separation/collapsing load will be 100-150 pounds, which is within human tolerance for head and face contact, based on a 1 square inch contact area. A grip with 4-inch height adjustment range is also to be incorporated, which is a feature that is not present on existing models.

Whatever the nature of the prototype cyclic stick design, it must first be structurally capable of controlling the aircraft under all conditions. Static pull testing will be performed on the prototype model to assure that a minimum of 200 pounds fore/aft load and 100 pounds lateral load can be withstood. Dynamic tests will then be performed to determine vertical breakaway loads and corresponding reactive head accelerations for the current production sticks and the prototype model. These will consist of simple pendulum tests with the mass and texture of the human head to be simulated at the striking end. Stick impact strike velocities of 30 and 20 ft/sec have been predicted by program SOM-LA for 95th and 50th percentile male occupants, respectively. The pendulum testing will be conducted using these impact velocities.

In future aviation weapon systems development, it is likely that advanced control systems will incorporate sidearm controllers and thus effectively eliminate the conventional cyclic stick as a cockpit strike hazard. In the meantime, retrofit of a well-designed crashworthy stick may be a very cost-effective approach to eliminating a major cause of crewman injuries and fatalities.

Advanced Crashworthy Landing Gear

Load-limiting landing gear are essential to accomplishing crashworthiness goals. From purely an economic viewpoint, the payoff from design for crashworthiness is primarily from reduction of aircraft mishaps, thus enhancing mission effectiveness through greater aircraft availability and avoidance of mishap costs. The MIL-STD-1290 requirement that the landing gear prevent fuselage/ground contact for impact velocities of at least 20 ft/sec for ±10 degrees roll and +15 degrees to -5 degrees pitch attitude, and combinations thereof, is the most significant factor in the realization of a cost-effective return on investment of design for crashworthiness. A landing gear that will prevent fuselage/ground contact at higher impacts than 20 ft/sec is certainly desirable from an aircraft damage prevention standpoint; however, this capability must take into account potential adverse system effects such as:

- Excessive landing gear and attachment weight with attendant decrease in aircraft performance
- Insufficient injury reducing energy attenuation in aircraft structure and seats for the case of impact with a retractable crashworthy gear in the retracted position
- A design that will result in excessive damage to dynamic components during landing gear load attenuation (This may be especially critical for the tilt prop/rotor concept.)

The required roll and pitch attitudes for impact without fuselage/ground contact evolved from a review of the survivable and partially survivable US Army rotary-wing accidents from January 1972 to December 1982. Figure 16 shows the roll frequency of occurrence when only impacts of ±25 degrees roll or less are considered (74 percent of all accidents). Figure 17 shows the pitch frequency of occurrence when only impacts of ± 30 degrees pitch or less are considered (92 percent of all accidents).

Although the AH-64 APACHE has entered limited production, the only fully operational helicopter with landing gear designed to the criteria of MIL-STD-1290 is the UH-60A BLACK HAWK. This landing gear configuration shown in Figure 18 consists of a main and tail gear, each having two stages and a trailing arm for increased stability during impacts with a longitudinal velocity component. The first stage comes into play for normal landings and hard landings up to 20 ft/sec. The second stage contributes to the total system energy absorption during crash impacts at vertical velocities up to 42 ft/sec.

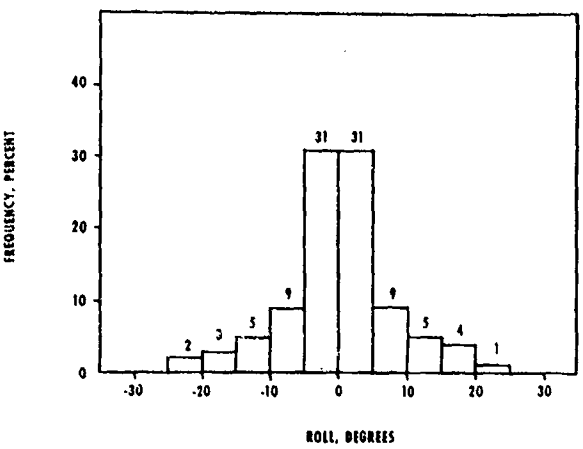

Figure 16. Impact Roll Angle Frequency.

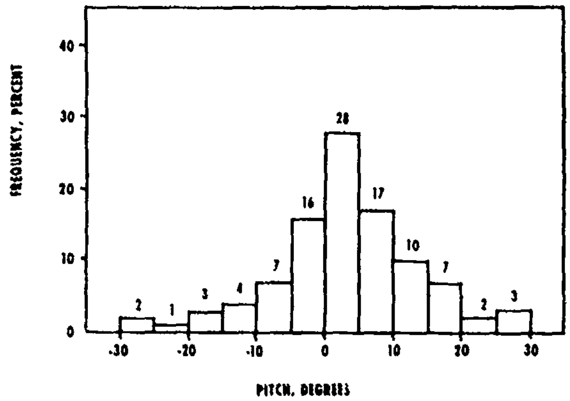

Figure 17. Impact Pitch Angle Frequency .

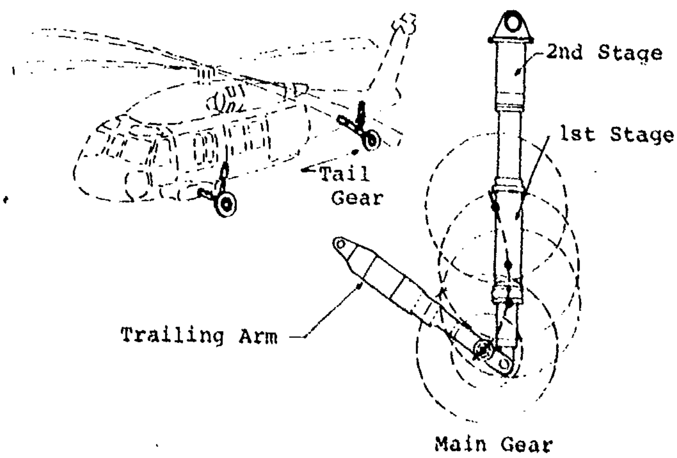

Figure 18. UH-60A Landing Gear .

Additional research is underway to critically analyze crashworthiness design criteria in light of cost and aircraft performance effects when one considers new-generation aircraft that may have retractable landing gear consisting of composite as well as metal components. The emergence of new high performance aircraft such as the tilt prop/rotor which has a higher disc loading than conventional helicopters may dictate the need for new landing gear design criteria.

Using accident rates and mean loss data furnished by the US Army Safety Center, an assessment was made of the benefits of incorporating into the AH-64 a landing gear capable of preventing fuselage-ground impact for vertical sink rates up to 20 ft/sec as compared with using a skid gear comparable to those of the AH-1, UH-1, and OH-58 helicopters. For an AH-64 fleet size of 500, it was calculated that there would be a 14-percent reduction in the accident rate, representing an estimated savings of nearly 570 million dollars for a 20-year fleet life cycle.

Crashworthy Fuel System

In the 1960's, postcrash fires were responsible for nearly 40 percent of all Army rotary-wing fatalities in potentially survivable accidents. In an effort to find a solution to this tragic problem, the US Army Applied Technology Laboratory conducted extensive efforts aimed at developing a crashworthy fuel system (CWFS) for Army helicopters. Particular attention was given to the derivation of fuel tank (bladder) material that was cut, tear, and rupture resistant while incorporating ballistic tolerance characteristics. A CWFS was developed that consisted of self-sealing breakaway valves/couplings; frangible attachments; self-sealing fuel lines; vent valves; cut, tear, and rupture resistant bladders; and a means of preventing postcrash fuel spillage at all postcrash attitudes. Due to the seriousness of the problem, the Army approved fleet retrofit of all helicopters with a CWFS as a safety issue.

With the advent of the Army crashworthy fuel system, postcrash fire statistics have been altered dramatically. During the past 12 years the incidence of thermal fatalities and injuries for CWFS-equipped helicopters has been essentially nonexistent. For example, during the period April 1970 to June 1976, for helicopters not equipped with a CWFS there were 65 thermal fatalities compared to just 1 for helicopters equipped with a CWFS. This is based on nearly the same number of accidents for each case. Since 1976 there have been no fatalities attributed to thermal injuries in potentially survivable accidents of Army helicopters. The highly successful application of this crashworthiness design feature not only has resulted in the prevention of numerous fatalities and a large loss of materiel but has had a very positive effect on aviator morale. In the development of a specification for a new aircraft system, some MIL-STD-1290 design criteria are scrutinized for applicability. However, this is not the case for criteria dedicated to crashworthy fuel systems.

YAH-63 Full-Scale Crash Test

Since the early 1960's, the Army has conducted a series of 41 full-scale crash tests of fixed- and rotary-wing aircraft. The objective of these tests has been to measure,

under controlled conditions, the dynamic structural and occupant response to a variety of crash parameters.

During July 1981 the Applied Technology Laboratory, in conjunction with the NASA-Langley Research Center (LRC) and the US Navy, conducted a full-scale crash test (T-41) of a YAH-63 attack helicopter. This prototype twin-engine, 15,000-pound gross weight class aircraft was acquired by ATL as residual hardware following the Advanced Attack Helicopter (AAH) fly-off competition. The crashworthy design of the YAH-63 is considered representative of that found in the Army's production advanced attack helicopter, the AH-64 APACHE. It is significant that this was the first crash test of an Army aircraft designed from its inception to incorporate most of the MIL-STD-1290 crashworthiness requirements, and it presented a unique opportunity to assess the effectiveness of actual crashworthiness design applications. Specific crashworthy features/experiments on T-41 were:

- Two-stage air/oil crashworthy landing gear
- Controlled crush belly structure
- Production AH-64 load-limiting crewseat incorporating 12-inch maximum stroke
- Developmental joint Army/Navy Inflatable Body and Head Restraint System (IBAHRS) on front crewman
- Prototype Integrated Helmet and Display Sight System (IHADSS) on front crewman
- Crashworthy fuel system including tanks, lines, fittings
- Tie-down strength of high-mass items sufficient for survivable crash loads
- Developmental Navy Flight Incident Recorder/Crash Position Locator (FIR/CPL)
- Developmental Army Accident Information Retrieval System (AIRS)
- NASA experimental package of Emergency Locator Transmitters (ELT's) and crash sensors

The crash test was accomplished using the cable swing/drop method at the NASA-LRC Impact Dynamics Research Facility. Cables were rigged to simulate a 50-ft/sec resultant impact vector of 95th percentile severity. The planned impact conditions were 30-ft/sec longitudinal velocity, 40-ft/sec vertical velocity, and 10 degree nose-up pitch attitude. Figure 19 shows the aircraft in its pretest pull-back position. Due to overestimates of aircraft drag, actual impact conditions were considerably more severe. The actual impact vectors were 36.2-ft/sec longitudinal velocity, 48.0-ft/sec vertical velocity for a 60.1-ft/sec resultant vector. As a result, the impact contained 44 percent more energy than the planned 95th percentile value which places it in the nonsurvivable range. A still sequence photo taken approximately 150 milliseconds after tail contact is shown as Figure 20.

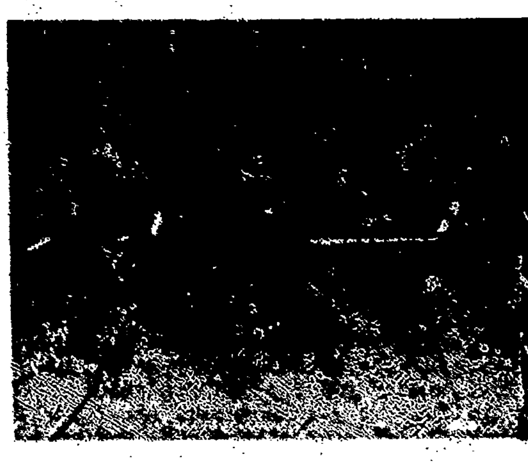

Figure 19. YAH-63 in Pull-Back Position Prior to Crash Test.

Figure 20. YAH-63 Approximately 150 Milliseconds After Impact.

The production bulkhead-mounted AH-64 crewseat traveled through its entire 12 inches of available stroke and "bottomed" on its stops due to the excessive vertical energy. The accelerometer traces which recorded the seat mounting bulkhead and the seat pan vertical accelerations are overlaid in Figure 21. Note particularly the seat pan bottoming pulse which remained above the 23 G Eiband criteria for 17 milliseconds. A dynamic response index (DRI) of 23 was later calculated. Ejection seat relationships established by the US Air Force indicate that this corresponds to a greater than 50 percent probability of spinal injury for the forward located copilot/gunner occupant. Detailed data relating to this test, along with a correlation of predictive versus actual results from use of computer program KRASH, are available in Reference 10.

In summary, the crashworthy landing gear, crushable structure, stroking seats, crashworthy fuel system, and high mass component retention all functioned successfully; and had the desired impact velocities (95th percentile survivable velocities) been obtained, non-injurious accelerative loadings would have been realized by the occupants.

UH-60A BLACK HAWK CRASHWORTHINESS EXPERIENCE

The UH-60A BLACK HAWK helicopter is the first operational Army helicopter designed from inception for crashworthiness using the requirements of the "Crash Survival Design Guide." The results have been dramatic, as evidenced by the following summary of a recent Class A UH-60A mishap:

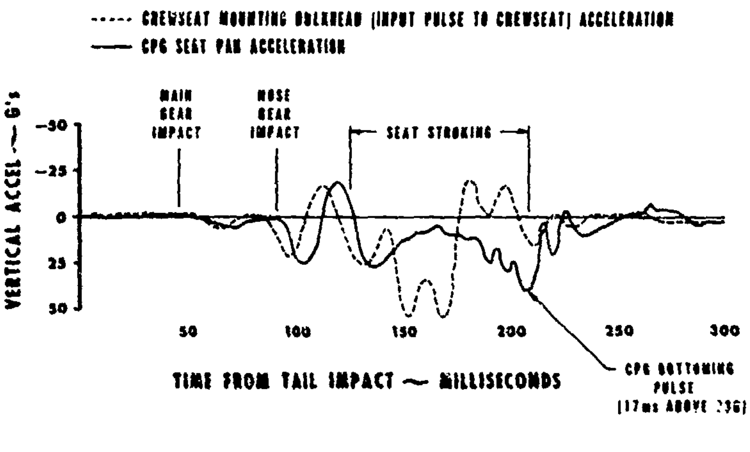

Figure 21. Copilot/Gunner (CPG) Bulkhead and Seat Pan Vertical Accelerations.

The aircraft crashed approximately 20° nose high with a horizontal velocity of 34 ft/sec and a vertical velocity of 49 ft/sec, giving a resultant velocity of 60.4 ft/sec, which for a noncrashworthy aircraft is considered a nonsurvivable impact. The impact sequence is shown in Figure 22.) The aircraft then rebounded with left yaw and right roll until resting on its right side up against a tree. The performance of the energy-absorbing tail and main landing gear and the stroking energy attenuating crew seats, coupled with the structural design for high mass component retention, resulted in maintaining a protective shell around the pilot and copilot and keeping the acceleration loadings in the cockpit below injurious levels. After the crash sequence, the copilot walked away from the aircraft with minor abrasions. The pilot suffered a broken leg and elbow as a result of flailing contact with the cyclic stick and seat wing armor, respectively. The crashworthy fuel system performed perfectly, which in this case was lifesaving in that the right side facing gunner seat occupied by the crew chief failed, resulting in critical injuries to this individual. A design modification is underway to improve the stroking gunner seat.

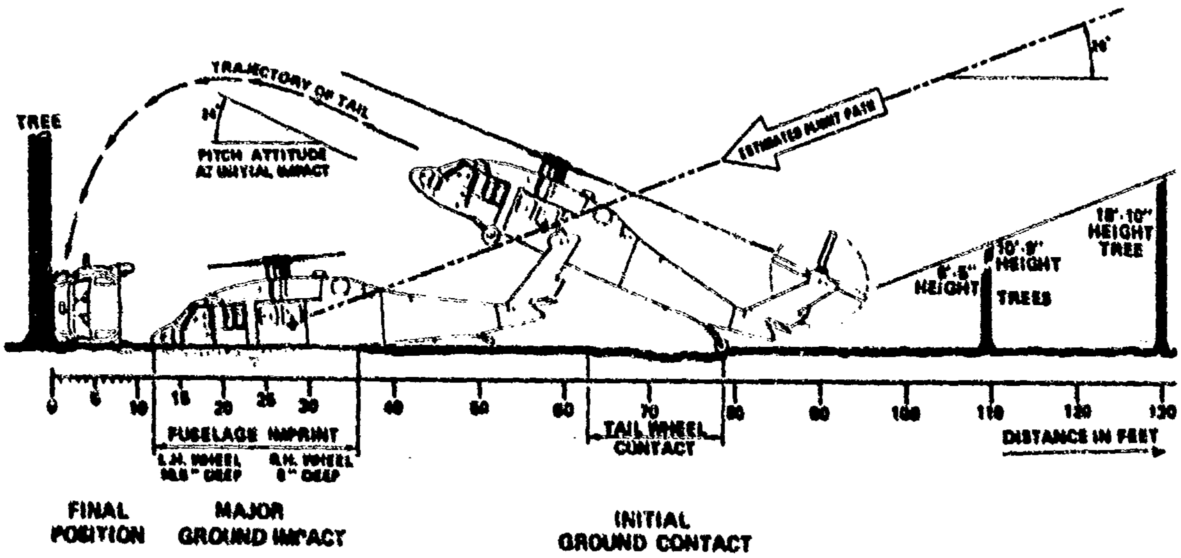

Figure 22. Crash Impact Sequence.

The UH-60A crashworthiness demonstrated in this mishap is remarkable and substantiates that design for crashworthiness will prevent many fatalities and injuries, and the loss of materiel during the life cycle of the BLACK HAWK fleet.

WEIGHT IMPACT AND EFFECTS ON LIFE-CYCLE COST

The many benefits realized by enhancing aircraft crashworthiness are not obtained without some impact on the weight of the aircraft. As discussed previously, this impact can be minimized during the development of completely new aircraft designs as compared to retrofitting crashworthiness features on existing aircraft. A brief survey of seven contemporary helicopter designs (a mix of civil and military designs) revealed varying degrees of integral crashworthiness, ranging from partial to nearly complete compliance with MIL-STD-1290. Weight increments attributed solely to crashworthy features fell between 1.59 and 3.68 percent of design gross weight. Within this range, the weight addition due to use of a crashworthy fuel system averaged 1.07 percent of the design gross weight. Thus, all protective features excluding the CWFS averaged 1.64 percent of design gross weight, which is considered to be an extremely small weight increment for such a high potential return in mission effectiveness. Of course, the weight increase due to crashworthiness design is reflected in aircraft system acquisition and operating costs.

From a total aircraft systems design/operational perspective, design for crashworthiness can have a significant impact on life-cycle cost, especially considering the fact that Army helicopters sometimes remain in the operational fleet for 30 years or more. In-house analyses have been conducted to assess the effects of crashworthiness on life-cycle cost, considering such variables as aircraft acquisition cost; cost of incorporating aircraft crashworthiness features; increased operational cost due to weight/performance penalties for the crashworthy features; personnel training cost; cost of crew injuries/fatalities in accidents; and accident-related property damage cost. Depending on the total cumulative flying hours per year for a fleet of helicopters, the break-even point, i.e., the point where the additional costs for incorporating crashworthy design features is offset, can occur in as little as 3 (wartime flying hour rate) to approximately 9 years (current peacetime flying rate). Beyond the break-even point the cost of owning and operating the fleet is reduced as a result of the crashworthy design. Again, these analyses consider only the costs associated with aircraft damage, personnel injuries/fatalities, and property damage. The total "costs" that are associated with increased mission effectiveness as provided by incorporating crashworthy design, although very difficult to define and quantify, have the potential of being highly significant in a positive sense.

RELATIONSHIP TO CIVIL AVIATION

In the civil aviation community, prevention of accidents has always been a high priority. However, even with technological advancements, increased mechanical reliability, improved pilot training, and intensive studies of accident causal factors, accidents do occur. Statistics from Reference 11 indicate that for one decade (1967-1976) the number of general aviation aircraft involved in accidents was equivalent to at least 38 percent of the total US production during that period. Estimates that an aircraft will be involved in an accident over a 20-year life range are as high as 60-70 percent.

Recognizing this accident probability, it makes sense to apply a worthwhile degree of crashworthiness to contemporary design philosophy. Because of differences in mission profiles, civil aircraft are normally flown somewhat differently than Army helicopters. The FAA Technical Center currently has an effort underway to better define the civil helicopter crash environment ("Rotorcraft Crashworthiness Scenarios," FAA Contract DTFA03-81-C-00035 with Simula, Inc., Tempe, Arizona, scheduled for completion in August 1983). The civil helicopter crash environments may not be sufficiently severe to justify using all of the MIL-STD-1290 crashworthiness design techniques that have been addressed in this paper. From a cost viewpoint the easiest to justify might be the use of state-of-the-art restraint and energy absorbing seat systems, although the crashworthy fuel system should perhaps be at the top of the priority listing of needed crashworthy features. As composite airframe structures become more attractive from a cost/weight standpoint, their demonstrated potential (Reference 12) to act as good energy absorbers should not be overlooked. Usually, however, design innovations to benefit crashworthiness will equate to a design in excess of the Federal Air Regulations (FAR's), which are intended as minimum requirements only rather than design goals. FAA Order DA 2100.1 clearly states, "Such standards do not constitute the optimum to which the regulated should strive" (Reference 13).

Finally, not to be overlooked in the civil area is the very real economic savings that can be gained (in concert with crashworthiness) from the inclusion of an energy absorbing (EA) landing gear. The potential Army savings were addressed earlier and would certainly, to a degree, apply in the civil market. Avoided materiel damage from hard landings alone should go a long way toward justifying an EA gear.

Some design practices, such as excellent protective structure around the occupant along with adequate restraint in agricultural aerial application airplanes, are now standard procedure. In time, it is hoped that a variety of meaningful crashworthiness improvements will be providing increasingly higher levels of occupant protection and damage avoidance.

MAJOR PROGRAM NEEDS

Considering the significant potential payoff for designing Army helicopters for improved crash survivability, the difficulty in retrofitting existing aircraft to make them more crash survivable, and the potential for crashworthiness criteria to significantly drive a new aircraft system design, the need exists to:

- Expand the Army aviation crash survivability program to develop more efficient concepts and measures for improving helicopter crashworthiness while having minimum impact on aircraft system weight, performance and cost.
- Continually improve/upgrade crashworthiness design criteria and standards, considering lessons learned from the UTTAS and AAH development programs; lessons learned from BLACK HAWK and APACHE helicopter operational experience; results from the various composite airframe programs; and new VTOL design concepts (e.g., tilt prop/rotor, which is a cross between the pure helicopter and fixed-wing aircraft).

CONCLUSION

- Too many US Army aircrewmen are still being fatally injured in potentially survivable accidents, and the percentage of major injuries and rate of materiel losses are still far too high.
- Technology and design criteria presently exist to significantly reduce these personnel injuries/fatalities and materiel losses associated with helicopter accidents.

- Army aviation mission effectiveness can be significantly enhanced through the application of crashworthiness design to Army helicopters.
- Life-cycle costs can be significantly reduced through the application of crashworthiness design to Army helicopters.
- MIL-STD-1290 has proved to be a viable, cost-effective requirements document.
- Although much higher levels of crashworthiness can be achieved in a complete new helicopter system design, significant improvements can be made in the crashworthiness of existing helicopters through retrofit programs.
- The need exists to continue to develop and apply efficient and economical measures for improving the crash survivability of existing and new-generation helicopters.
- The need exists to continually improve/update helicopter crashworthiness design criteria and standards.
- Military helicopter crashworthy features are directly applicable to the civil/commercial helicopter fleet.

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